

Background effects on reconstructed WIMP couplings

Chung-Lin Shan

Institute of Physics, Academia Sinica

No. 128, Sec. 2, Academia Road, Nankang, Taipei 11529, Taiwan, R.O.C.

E-mail: clshan@phys.sinica.edu.tw

Abstract. In this talk, I presented effects of small, but non-negligible unrejected background events on the determinations of WIMP couplings/cross sections.

1. Introduction

Residue background events which pass all discrimination criteria and then mix with other real signals in data sets are one of the most important issues in all underground experiments. Hence, as a more realistic study, we reexamine our model-independent data analysis methods for determining (ratios between) different couplings/cross sections of Weakly Interacting Massive Particles (WIMPs) on nucleons in direct Dark Matter detection experiments [1, 2] by taking into account small fractions of unrejected background events [3, 4].

2. Background effects on reconstructed WIMP–nucleon couplings/cross sections

In this section I present simulation results of the reconstructed (ratios between) different WIMP–nucleon couplings/cross sections with mixed data sets from WIMP-induced and background events. $2(3) \times 5,000$ experiments have been simulated by the Monte Carlo method. Each experiment contains 50 total events on average. The experimental threshold energies of all experiments have been assumed to be negligible and the maximal cut-off energies are set the same as 100 keV. Note here that both signal and background events are treated as WIMP signals in the analyses.

2.1. Reconstructed $|f_p|^2$

In Fig. 1 I show the reconstructed squared SI WIMP–nucleon couplings $|f_p|^2$ as functions of the input WIMP mass. The SI WIMP–nucleon cross section is set as 10^{-8} pb, the commonly used value for the local WIMP density $\rho_0 = 0.3$ GeV/cm³ has been used for both data generating and analyzing. A ⁷⁶Ge target has been used for reconstructing $|f_p|^2$, whereas another *independent* data set of ⁷⁶Ge and one of ²⁸Si have been used for determining the needed WIMP mass. The background ratios shown here are no background (dashed green), 10% (long-dotted blue) and 20% (solid red).

It can be seen here that, not surprisingly, due to extra unexpected background events, the larger the background ratio in the analyzed data set, the more strongly overestimated the reconstructed SI WIMP–nucleon coupling for all input WIMP masses. Moreover, for a heavy target, e.g., ⁷⁶Ge, it has been found that this overestimate could be at the strongest for WIMP masses between 30 GeV and 100 GeV, once the background ratio rises to $\gtrsim 20\%$ [3].

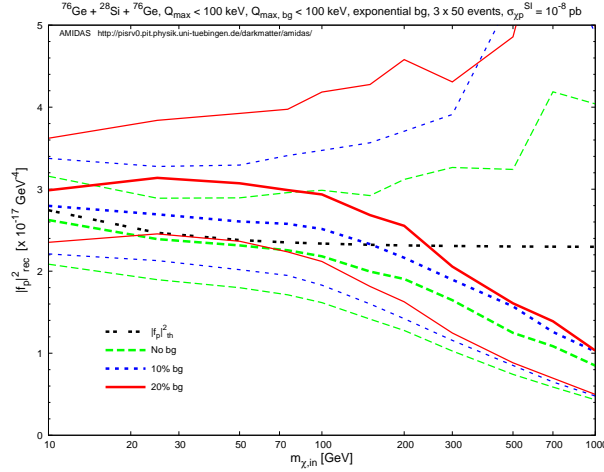


Figure 1. The reconstructed squared SI WIMP–nucleon couplings $|f_p|^2$ and the lower and upper bounds of their 1σ statistical uncertainties as functions of the input WIMP mass reconstructed with a ^{76}Ge target. Another *independent* data set of ^{76}Ge and one of ^{28}Si have been used for determining the needed WIMP mass. The double-dotted black curve is the theoretical value of $|f_p|^2$ corresponding to the fixed SI WIMP–nucleon cross section $\sigma_{\chi p}^{\text{SI}} = 10^{-8}$ pb. The background ratios shown here are no background (dashed green), 10% (long-dotted blue) and 20% (solid red) (plot from Ref. [3]).

Nevertheless, Fig. 1 shows that one could in principle estimate the SI WIMP–nucleon coupling with an uncertainty of a factor $\lesssim 2$ by using data sets with maximal 20% background events.

2.2. Reconstructed a_n/a_p

The left frame of Figs. 2 shows the reconstructed a_n/a_p ratios with $n = -1$ (dashed blue), 1 (solid red), and 2 (dash-dotted cyan) as functions of the input a_n/a_p ratio for the case of a dominant SD WIMP–nucleus interaction. A combination of $^{19}\text{F} + ^{127}\text{I}$ targets has been used. The background ratio in the analyzed data sets is 20%. The mass of incident WIMPs has been set as $m_\chi = 100$ GeV.

It can be seen that, due to the non-negligible background events, the reconstructed a_n/a_p ratios (for this $^{19}\text{F} + ^{127}\text{I}$ target combination) become now underestimated; in fact, the larger the background ratio the larger this systematic deviation of the reconstructed a_n/a_p ratios [4]. Meanwhile, for the same data sets, the larger the n value (or, equivalently, the larger the used moment of the WIMP velocity distribution), the smaller this systematic deviation [4]. This (in)compatibility between the reconstructed a_n/a_p ratios with different n could thus offer us a simple check for the purity/availability of our data sets.

On the other hand, in the right frame of Figs. 2 I show the reconstructed a_n/a_p ratios for the case of a general combination of both SI and SD WIMP interactions. Here we analyzed the same data sets with (solid red) and without (dashed blue, $n = 1$) considering the extra SI interaction term.

It can be seen that the (in)compatibility between the reconstructed a_n/a_p ratios under different assumptions about the WIMP–nucleus interactions becomes larger. Moreover it has been found that, firstly, with an increased background ratio the systematic deviations and the statistical uncertainties of the reconstructed a_n/a_p ratio for considering the general combination of the SI and SD WIMP interactions (solid red) grow only (very) slightly [4]. Secondly, once residue background events exist regularly between the experimental minimal and maximal cut-off energies or (even better) (mostly) in high energy ranges, one can in principle estimate the

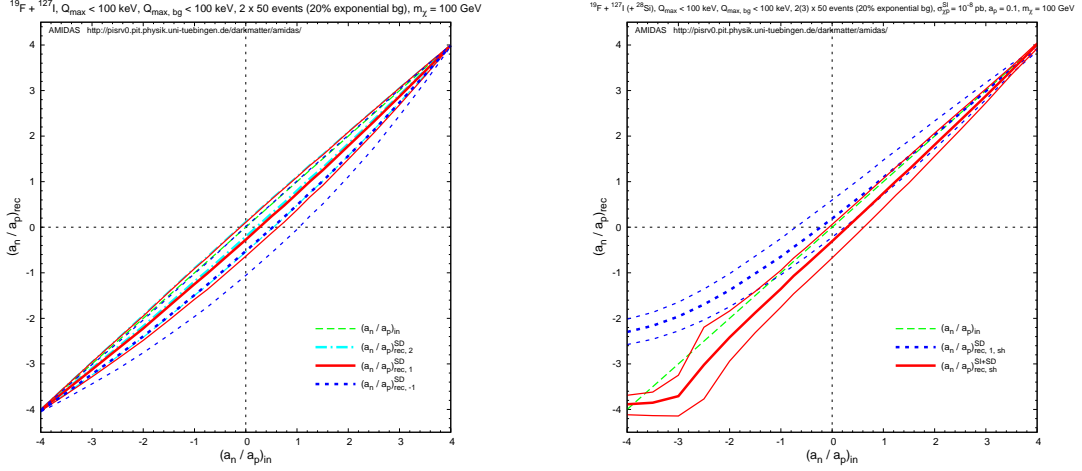


Figure 2. The reconstructed a_n/a_p ratios and the lower and upper bounds of their 1σ statistical uncertainties as functions of the input a_n/a_p ratio. Left: a SD-dominant WIMP–nucleus interaction with $n = -1$ (dashed blue), 1 (solid red), and 2 (dash-dotted cyan); right: adding a non-zero SI WIMP–nucleus interaction, analyzed with (solid red) and without (dashed blue, $n = 1$) taking into account this term. The mass of incident WIMPs has been set as $m_\chi = 100$ GeV. The input SI WIMP–nucleon cross section and the input SD WIMP–proton coupling have been set as $\sigma_{\chi p}^{\text{SI}} = 10^{-8}$ pb and $a_p = 0.1$, respectively. The background ratio in the analyzed data sets is 20% (plots from Ref. [4]).

ratio between two SD WIMP–nucleon couplings (pretty) precisely *without* worrying about the non-negligible backgrounds [4].

Moreover, by considering different input WIMP masses, a WIMP–mass independence of the reconstructed a_n/a_p ratios as well as of their statistical uncertainties with even non-negligible background events has been observed [4]. With data sets of $\lesssim 20\%$ background ratios, the reconstructed 1σ statistical uncertainty intervals could in principle always cover the input (true) a_n/a_p ratios pretty well for WIMP masses $\gtrsim 25$ GeV [4].

2.3. Reconstructed $\sigma_{\chi(p,n)}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$

Figs. 3 show the reconstructed $\sigma_{\chi p}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$ (left) and $\sigma_{\chi n}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$ (right) ratios as functions of the input a_n/a_p ratio. It can be seen that, interestingly, while the $\sigma_{\chi p}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$ ratios reconstructed with F + I + Si targets become more and more strongly underestimated with an increased background ratio, those reconstructed with Na + Ge targets become in contrast more and more strongly overestimated [4]. Meanwhile, more interestingly, while the $\sigma_{\chi n}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$ ratios reconstructed with F + I + Si targets become more and more strongly underestimated with an increased background ratio for all input a_n/a_p values, those reconstructed with Xe + Ge targets become more and more strongly *underestimated* for $a_n/a_p \gtrsim 0$ and more and more strongly *overestimated* for $a_n/a_p \lesssim 0$ [4]. Nevertheless, with data sets of $\lesssim 20\%$ background ratios, the reconstructed 1σ statistical uncertainty intervals could in principle always cover the input (true) $\sigma_{\chi(p,n)}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$ ratios pretty well [4].

3. Conclusions

In this article we reexamine the model-independent data analysis methods introduced in Refs. [1, 2] for determining (ratios between) different WIMP–nucleon couplings/cross sections from measured recoil energies of direct detection experiments directly by taking into account

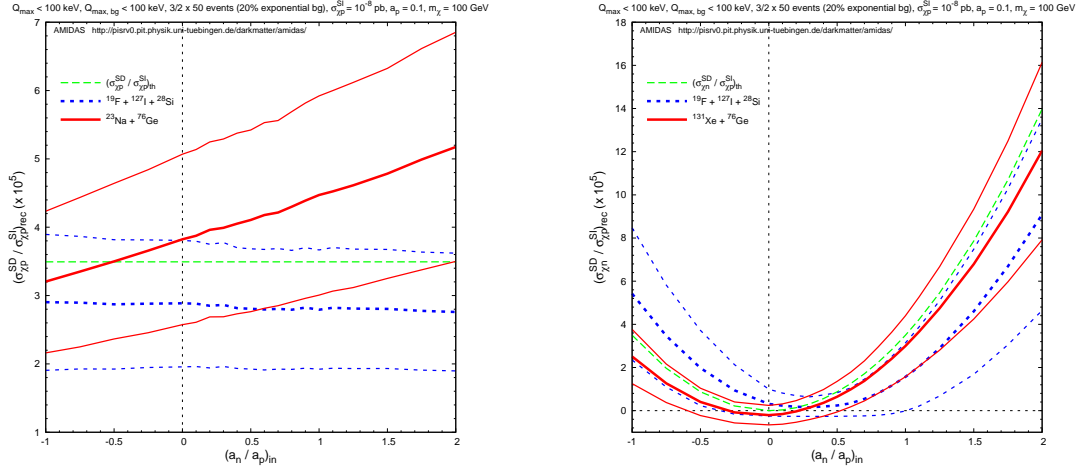


Figure 3. The reconstructed $\sigma_{\chi p}^{\text{SD}}/\sigma_{\chi p}^{\text{SI}}$ (left) and $\sigma_{\chi n}^{\text{SD}}/\sigma_{\chi n}^{\text{SI}}$ (right) ratios and the lower and upper bounds of their 1σ statistical uncertainties as functions of the input a_n/a_p ratio. The dashed blue curves indicate the ratios reconstructed with F + I + Si, whereas the solid red curves indicate the ratios with ^{76}Ge and combined with ^{23}Na (left) and ^{131}Xe (right). Parameters are as in the right frame of Figs. 2 (plots from Ref. [4]).

small fractions of residue background events.

Our simulations show that, due to extra unexpected background events, the SI WIMP–nucleon coupling would be overestimated; nevertheless, the maximal acceptable background ratio in the analyzed data set of $\mathcal{O}(50)$ total events could be $\sim 20\%$.

On the other hand, the maximal acceptable background ratio for determining the ratio of the SD WIMP coupling on neutrons to that on protons is also $\sim 20\%$. However, the larger the relative strength between the SD WIMP–nucleus interaction to the SI one, the smaller the systematic deviations as well as the statistical uncertainties. Moreover, it has also been found that, by taking different assumptions about the relative strength between the SI and SD WIMP–nucleus interactions, and/or using different moments of the one-dimensional WIMP velocity distribution, there would be an (in)compatibility between different reconstructed a_n/a_p ratios, which could allow us to check the purity/availability of the analyzed data sets.

Furthermore, we found also that only background events in the lowest energy ranges could affect the reconstructions (significantly); those in high energy ranges would almost not change the reconstructed ratios or only very slightly.

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